PROLINE-CE

WORKPACKAGE T2, ACTIVITY T2.2

IMPLEMENTATION OF BEST PRACTICES FOR WATER PROTECTION IN PILOT ACTIONS

D.T2.2.2 PARTNER-SPECIFIC PILOT ACTION DOCUMENTATIONS

PILOT ACTION: PA2.5 Neufahrn bei Freising

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1. Introduction

Best management practices (hereinafter BMPs) for drinking water protection and management derived from T1 were reviewed and relevant BMPs were selected for particular pilot action. Implementation status of BMPs was verified in Pilot Actions (T2); in case of lacks identified, possibilities of improvement and implementation were also assessed. Drinking water protection and management and best practices are strategically implemented in the pilot actions, in order to achieve a function-oriented land-use based spatial management for water protection at the operational level. Measures and actions were analysed and proposed concerning mitigation of extremes and achieving a sustainable drinking water level. PROLINE-CE pilot actions reflect the broad range of possible conflicts regarding drinking water protection, such as: forest ecosystem service function; land-use planning conflicts; flooding issues; impact of climate change and land-use changes; demonstration of effectiveness of measures including ecosystem services and economic efficiency.

Review of main land use conflicts and BMPs on Pilot Action level has already been done in Pilot Action BMPs reports, which were a basis for *D.T2.1.2 Transnational case review of best management practices in pilot actions*. Description of natural characteristics of Pilot Site is presented in *D.T.1.4 Descriptive documentation of pilot actions and related issues*.

Activities within Pilot Action were done according to set-up which was described in *D.T2.1.5 Set-up report about adaptation of the transnational concept to pilot action level*.

The Deliverable *D.T2.2.2 Partner-specific pilot action documentations* presents final Pilot Action report regarding the management actions examined in the Pilot Action, description of conducted activities and identified solutions for case-specific adaptations of management concepts. This report presents final work report regarding the implementation of best management practices for drinking water protection in pilot action PA2.5 Neufahrn bei Freising.

2. Testing of BMPs in Pilot Action

2.1. Objective(s) of Pilot Action

The pilot area Neufahrn bei Freising represents the groundwater recharge zone that is related to the groundwater pumping wells of the local water supplier. Groundwater is used both for agricultural activities and as water supply for industrial usage (upper aquifer) and as drinking water supply (lower aquifer) in the area. Operational changes in agricultural practices are commonly related to economical driving forces, leading to the fact that agricultural land management is regulated by economic welfare. However, the supply of high-quality freshwater counts as one of the most important fundamental needs, although it is not always respected when adapting agricultural and industrial practices.

Land management adaptations can occur fairly quickly, while their impacts on water quality and quantity are notable only years after. Thus, we need predictive and planning tools to investigate possible impacts of land use changes on water resources, so that land management plans can directly consider whether or not a planned action affects the water resources. Hydrological models nowadays enable coupled simulations of land and surface water management and subsurface hydrological processes. However, such models require a representative amount of data to realistically set up a plausible modelling concept. A monitoring program for water quality and water quantity data with a high spatial and temporal resolution represents a valuable system to gain an in-depth understanding of the natural system as well as to support model implementation and its prediction ability. Once developed, land management scenarios can be tested with the model and management plans considering synergies for water protection and economic welfare can be elaborated. Therefore, we consider a continuous monitoring in both, surface water and groundwater, as well as an integrated hydrological modelling framework to support site-specific solutions and stakeholder engagement as the two Best Management Practices for the pilot area Neufahrn bei Freising.

The main objectives are 1) setting up a comprehensive data base including existing data and filling data gaps by installing new measuring points 2) set up of an integrated hydrological modelling framework, 3) integration of past land use changes and evaluation of the models' functionality and 4) testing, possible future land management scenarios and their impacts on the water resources.

2.2. BMPs of Pilot Action

▪ Identified GAP provoking action	
GAP short name	**Continuous conversion of (permanent) grasslands**
GAP short description	A spread conversion of, mostly permanent, pastures started due to socio-economic changes in the late 1980's to early 1990's. Since then, several agricultural land use changes occurred that are strongly related to socio-economic fluctuations in the pilot area.
▪ Best management Practice / Management Action	
Name of BMP	**Continuous monitoring in both, surface water and groundwater**
Type of land use regarded	Agriculture
Location	Plain area
BMP description	Enlarge the infrastructure of the existing monitoring network towards a higher temporal and spatial resolution of relevant water quality and quantity data. Therefore, in a first instance, an overview over existing data needs to be gathered to identify relevant, i.e. site-specific and question-related, data gaps. Once relevant gaps were identified, suitable installation points for new measuring devices have to be found and the temporal resolution at which each

	measuring device should operate have to be set. Finally, the enhanced monitoring program can start. Generally, the value of a continuous monitoring of water-related data should be more emphasized in existing policy guidelines. Water suppliers as well as water authorities should receive incentives to better manage available data and to collect hydrological data more frequently and with a higher spatial resolution.	
Advantages of this BMP in PA	A comprehensive monitoring of relevant hydrological data provides valuable insights into the functioning of a regarded catchment or study area. Well-managed and highly temporally and spatially resolved data form the base for an in-depth understanding of the ongoing hydrological processes as well as for understanding the effects of external impacts, such as land use and climate change, on the natural system. No adaptation of existing land use management practices required.	
Challenges of this BMP in PA	The greatest challenge, in our opinion, is to implement a better structure for data management between and in different responsible authorities. Moreover, data transfer from privately owned measuring devices should be made more interesting for the owners to share their data. Generally, we found complex organizational structures while trying to obtain the permit for the installation of new monitoring points as well as a resistance of some individuals in processing the requests for the installation of new monitoring points.	
Relevance	Water protection functionality	High
	Cost of the measure	Low
	Duration of implementation	Short
	Time interval of sustainability	Long
Limitations	No	
Comments	----	
References / sources	World Health Organization & United Nations Environment Programme. (1996). Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programs / edited by Jamie Bartram and Richard Ballance. London: E & FN Spon. http://www.who.int/iris/handle/10665/41851	

▪ Identified GAP provoking action	
GAP short name	**Lack of public engagement in development of action plans**
GAP short description	Despite some approaches in the legal framework of how to engage the public in the development of action plans, more flexible and integrative concepts of how to involve public stakeholders in the decision-making procedure are missing

Best management Practice / Management Action	
Name of BMP	**Finding site-specific solutions by using a hydrologic model with a graphical user interface in a participative approach**
Type of land use regarded	Agriculture
Location	Plain area
BMP description	Public engagement should take place already at early steps of the decision process. The development of action plans for the implementation of protection plans should be carried out in close cooperation with land owners that are directly affected by future regulations in the delineated protection zones. Possible actions and measures should be elaborated based on land owner's possibilities to use existing structures/facilities/machinery. However, a tool is needed on which stakeholders can jointly elaborate site-specific action plans and which can be used to evaluate the effects of planned actions at the same time. Therefore, we propose hydrological models as BMP here; the model can be used as a participative approach given a graphical user interface (such as FREEWAT) and to test how any kind of changes (such as land use changes) affect the hydrological processes in the considered area. Moreover, a fully coupling between monitoring and model can provide a powerful tool for on-the-fly decision making. Modeling results can provide relevant information for stakeholders regarding water quantity and quality and support decision makers in the implementation procedure for final management plans. In close cooperation between land owners and decision-makers, site-specific solutions can be found which can reduce the trade-offs between all stakeholders.
Advantages of this BMP in PA	Engaging local stakeholders and affected land owners in the process of finding adequate, site-specific solutions can increase the acceptance of the finally proposed measures and potentially decrease the costs for compensation measures. Due to their daily business, land owners know best about potentials of how to restructure or manage their field operations. The hydrological model sets a joint framework all stakeholders may work with (given a short introduction) and helps to evaluate the impacts of a planned management practice. The proposed measure can significantly reduce the existing mistrust between authorities and land owners.
Challenges of this BMP in PA	Little involvement generally leads to less acceptance of planned measures that could be decreased if site specific actions would be planned in cooperation with the affected land users. In this context, the stakeholders noticed that when their interests are affected by the implementation of a measure, then local stakeholders show a higher acceptance than those who just operate their business in the respective region (and live somewhere else). Local stakeholders feel more the problematic issues about planned measures and recognize the advantage of a solution, while stakeholders who are not so

	much connected to the territory do not feel the related danger/problem.	
Relevance	Water protection functionality	High
	Cost of the measure	Medium
	Duration of implementation	MEDIUM-Short
	Time interval of sustainability	Long
Limitations	No	
Comments	----	
References / sources	Hanson et al. (2014), FREEWAT project (www.freewat.eu)	

3. Activities in the Pilot Action

In the framework of PROLINE-CE, we created a broad network of stakeholders in the community Neufahrn bei Freising. The stakeholder panel includes land owners, farmers, the local water supply, local administration and general public. We discussed with people about land management practices today and in the past and thus, we got a general impression of what changes related to land management practices occurred in the pilot area.

We identified hydrological modelling and data monitoring as the most important and suitable Best Management Practices for the pilot area to continuously evaluate any changes occurring related to land and water management practices. The hydrologic model is said to enable producing on the fly results for land management implementation plans and supports decision-making. Therefore, we set up a first hydrological model that should be used as a base for the implementation of future land and water management scenarios. Moreover, we will develop different land management scenarios based on the stakeholder engagement to evaluate the potential of public engagement in finding site-specific solutions. To make the model applicable to investigate land use change impacts on river – groundwater interactions, we started to monitor the Isar river water stage at two points in the pilot area (southern and northern model boundary). Moreover, a further piezometer will be installed close to the river in order to better - understand the hydrological processes in the pilot area. The implementation of the monitored data helps to enhance the representation of surface water properties in the model and to more reliably simulate the hydrological processes related to the Isar river. A more detailed description of the model implementation follows in chapter 3.1.

In terms of water quality, we performed comprehensive data analysis of about 50 hydrochemical parameters that were measured in the shallow groundwater between 1978 and 2017 and in the deep groundwater between 2003 and 2016. Different methods of statistical analysis (such as descriptive analysis, ANOVA, correlation analysis) were applied to study the main factors affecting groundwater quality in the pilot area. The primary results indicated that the deep groundwater is of better quality as compared to the shallow groundwater. However, to detect the impact of land use variations and groundwater management policies on groundwater quality, we especially focused our analysis on the nitrate concentration time series obtained from the shallow groundwater. Therefore, trend analysis (Mann-Kendall test) was applied on the nitrate data to reveal and quantify the role of human activities on groundwater quality. Long-term nitrate observation in shallow well number 1 (as the most complete nitrate monitoring from 1981 to 2017) shows a decreasing trend, from nitrate value near 45 mg/L in 1981 to near 20 mg/L in 2017 (see section 3.2). However, nitrate concentrations showed intensive fluctuations during 37 years of monitoring, probably due to variations in precipitations, runoff, and human activities.

Moreover, the pattern of the historical nitrate contamination was used to predict nitrate concentration in coming years or decades. Although the prediction method applied in this study (such as ARIMA) was used to predict nitrate values in the near future, the presence of gaps and irregular sampling patterns introduced some errors in the prediction results, which are under consideration. A more detailed description of the water quality investigations follows in chapter 3.2.

3.1. Hydrological modeling with the One-Water Hydrologic Flow Model framework (OWHM)

A first hydrological model was set up for the pilot area Neufahrn bei Freising with MODFLOW-OWHM (Hanson et al., 2014). MODFLOW-OWHM is a modular framework, integrating different hydrological systems and processes as packages, which can flexibly be merged.

The existing model comprises a one-layer that represents the Quarternary (shallow) groundwater aquifer. It comprises the domain shown in Fig. 1. The eastern boundary is limited by the Isar river; thus, the model furthermore implements this fluvial system to enable the simulation of the exchange processes that occur at the surface water – groundwater interface. Next, the southern and northern boundary are both implemented based on measured groundwater levels in the piezometers 16604, 16606, 16609 and 166114. The western boundary represents a no flow boundary, which means that the model assumes no transboundary fluxes. Furthermore, the processes occurring in the unsaturated zone, i.e. infiltration and evapotranspiration, are considered in the whole model domain. Moreover, the model structure incorporates the three shallow wells of the water supply association Freising-Süd (Schuler, 1992).

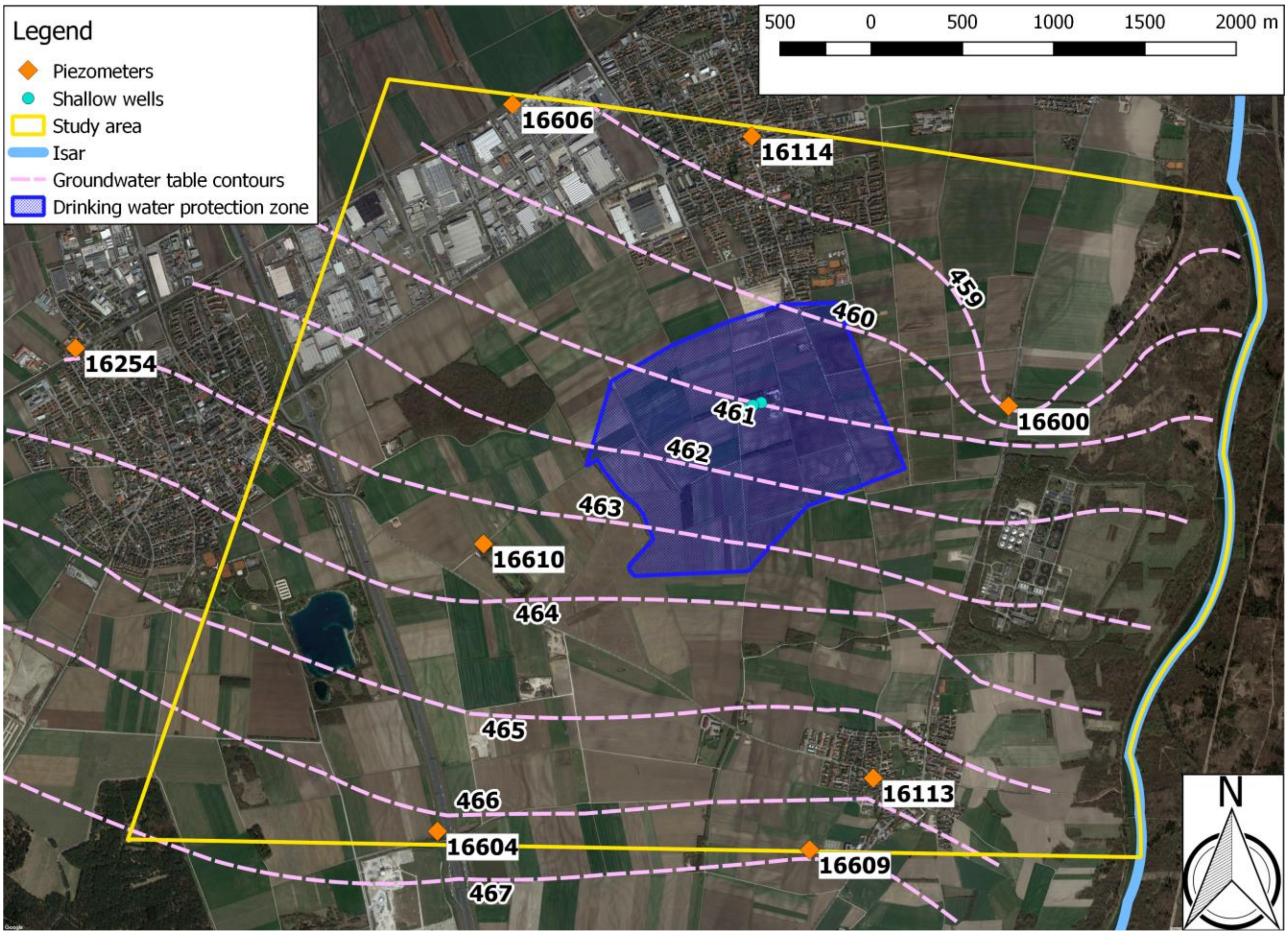

Figure 1: Modeling domain of the pilot area Neufahrn bei Freising. Basemap: Bayerische Vermessungsverwaltung (2018).

In this first hydrological model, we assumed homogeneous and isotropic conditions with a hydraulic conductivity in the range of 0.06 ms-1 to 0.0006 ms-1 and the storage parameter specific yield to in the range of 0.2 m-1 and 0.25 m-1 for the whole shallow aquifer system. Due to data availability, the model was calibrated and validated during the period from 11/1979 to 11/1985 and from 11/1985 to 11/1990. The measuring data for the piezometers used as boundary conditions and those used for the model performance evaluation, as well as the pumping rates from the shallow wells were kindly provided the water supply association Freising-Süd (LIT).

We calibrated the model and validated the model performances with the help of two observation wells that are located in the pilot area: well 16610 and 16113 (Fig. 1). A third well, well 16600, could not be used for the model performance evaluation, since a local groundwater withdrawal (isolines in Fig. 1) close to this well makes a realistic assessment of the model results impossible. To objectively assess the model performances, we used the Nash-Sutcliffe Efficiency (NSE) and the Mean Absolute Error (MAE) as evaluation criteria, which are calculated by the following equations:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{sim}^{i} - Q_{obs}^{i})^2}{\sum_{i=1}^{n}(Q_{obs}^{i} - \overline{Q_{obs}})^2} \quad \text{Eq. 1}$$

$$MAE = \frac{\sum_{i=1}^{n}(Q_{sim}^{i} - Q_{obs}^{i})}{\mathrm{n}} \quad \text{Eq. 2}$$

Here, Q_{sim}^{i} and Q_{obs}^{i} are the simulated and observed discharge at time step i and $\overline{Q_{obs}}$ represents the mean value of the observed discharge during the considered time period.

The best model fit at both calibration wells was obtained with a hydraulic conductivity of 0.009 ms-1 and a specific yield of 0.24 m-1.

The NSE and MAE for the calibration and validation period are presented in Table 1. The objective evaluations and the simulated and observed head time series (Fig. 2 and 3) highlight a good agreement between the measured and simulated groundwater levels in terms of the simulated dynamics. Although the simulated water level is slightly underestimated, it is possible to draw the conclusion that the model represents a good base for further model expansions.

Table 1: Objective evaluation results of the model calibration and validation.

Evaluation criteria	16610		16613	
	Calibration	Validation	Calibration	Validation
NSE [-]	0.98	0.98	0.95	0.94
MAE [ls^{-1}]	0.12	0.15	0.31	0.33

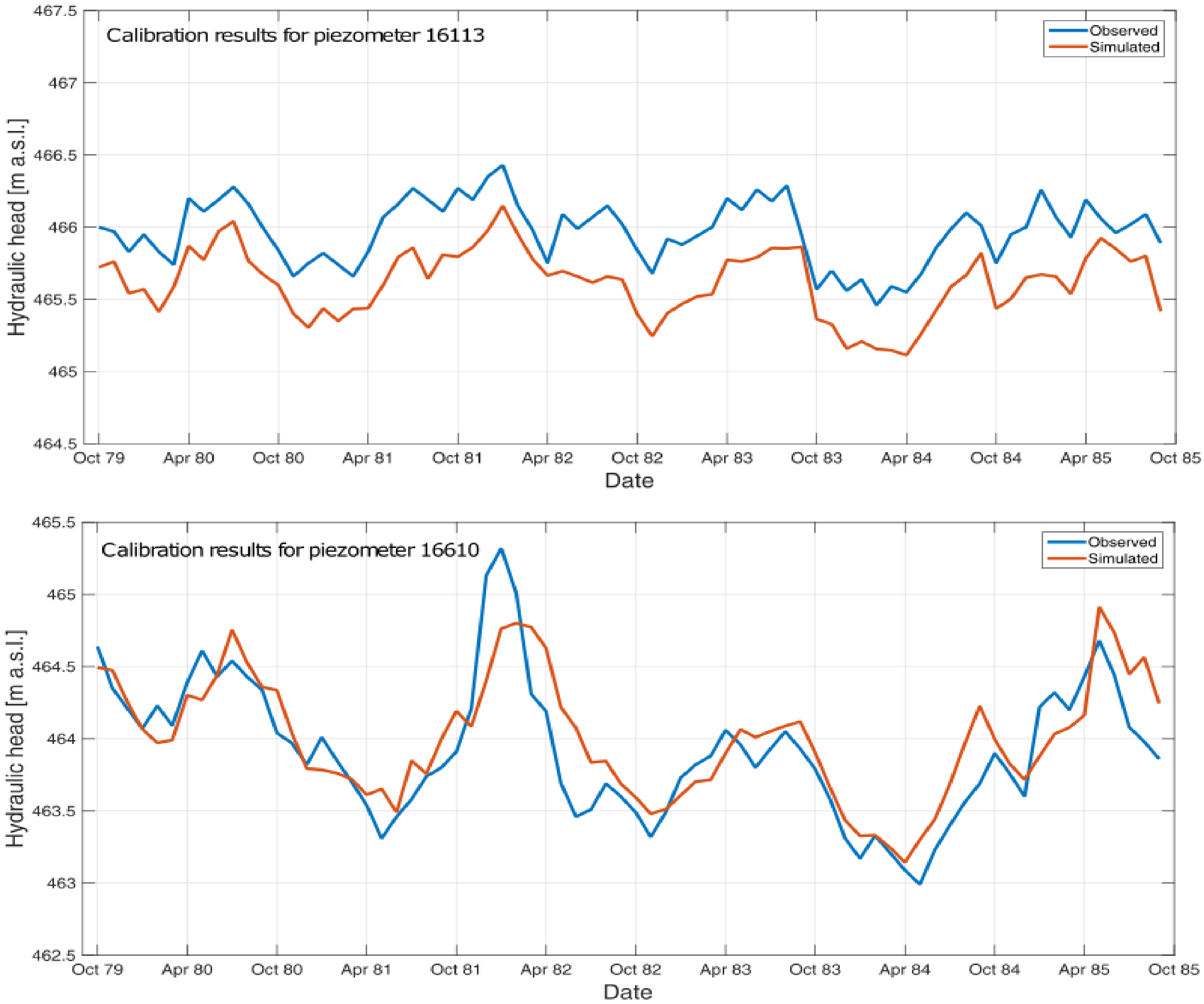

Figure 2: Simulated and measured groundwater levels at wells 16610 and 16613 during the calibration period.

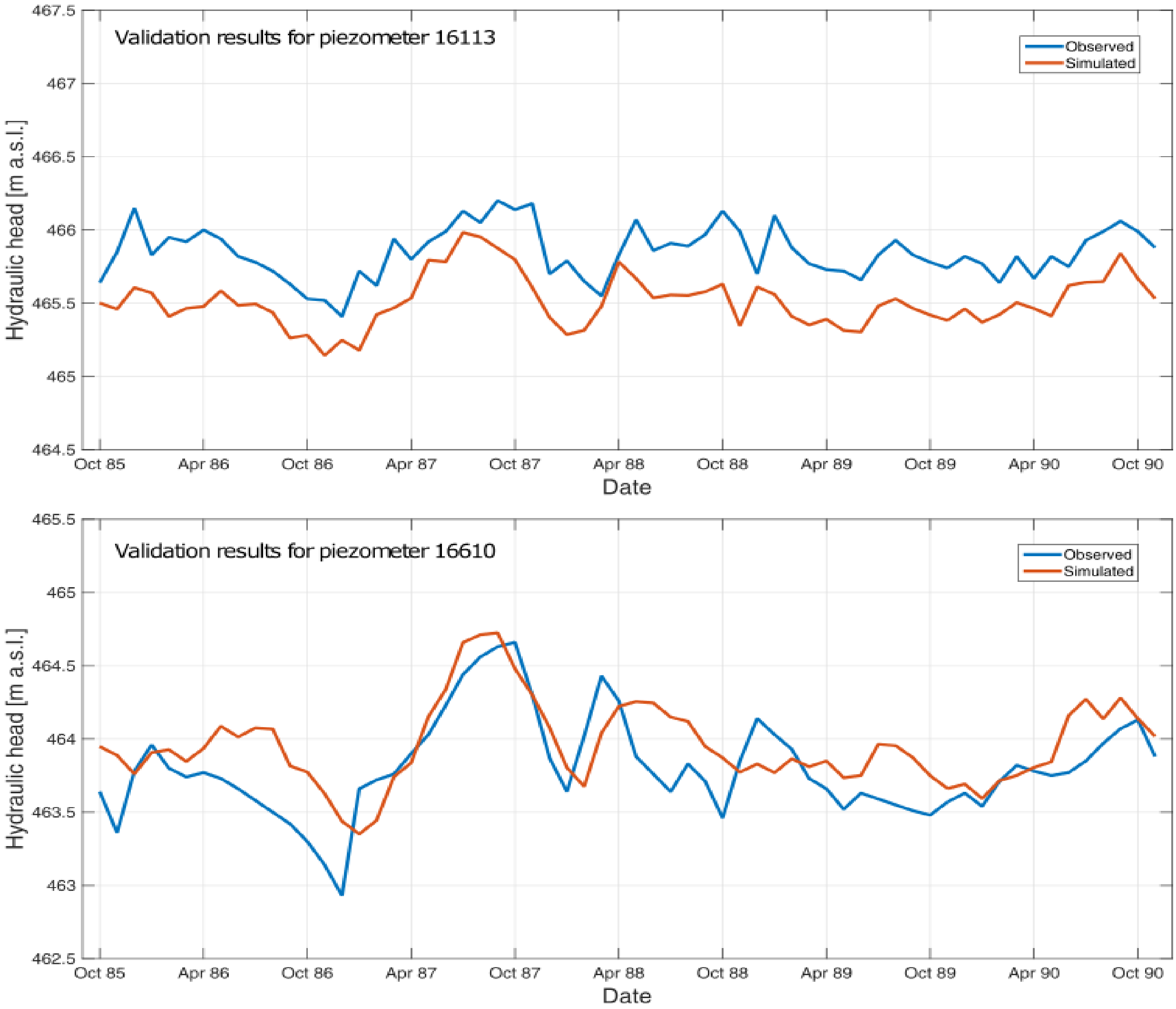

Figure 3: Simulated and measured groundwater levels at wells 16610 and 16613 during the validation period.

In order to employ the model for decision-making purposes, we first had to update the boundary conditions to include more recent data. Additionally, past and current land use practices need to be implemented into the model. To do so, the modelling framework of OWHM incorporates a package called Farm Process (FMP), which simulates the water demand of different crop types and the actual water supply. Supply, in this context, includes all water provided by the groundwater, precipitation and applied water (such as irrigation) to fulfil the crops' demand for evapotranspiration. That supply and demand framework offers a variety of possible applications: 1) simulating a crops' water demand together with the actual supply enables a quantification of irrigation needed to ensure a profitable plant growth, 2) the quantification of the crops' water demand allows to investigate the spatiotemporal impacts of land use actions on groundwater recharge, 3) a detailed knowledge about areas having a high demand of water helps to find site-specific solutions in land management plans, 4) balancing the water demand and supply on the land surface can help to improve the understanding of land use change impacts on surface water – groundwater interaction.

The data for setting up the FMP package of OWHM was kindly provided by the LfL (2018). The provided data include detailed information about the spatial and temporal distribution of planted crops from 2011 to 2017. Fig. 4 illustrates the general procedure of how the provided land use information was integrated into the modelling framework.

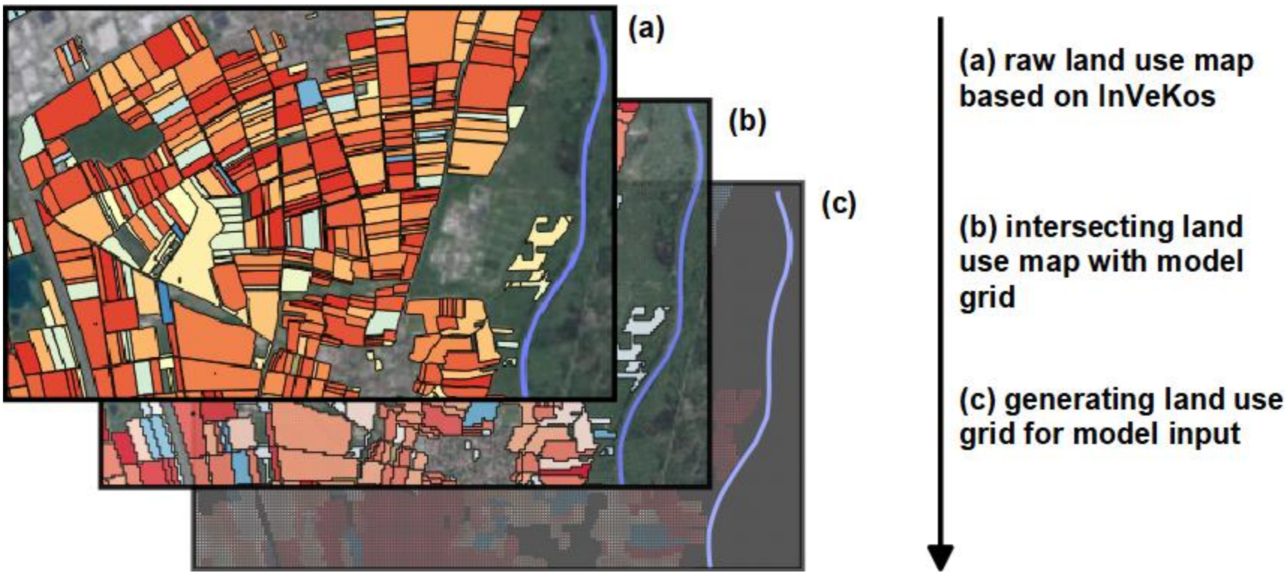

Figure 4: Implementation of InVeKos land use data (LfL, 2018) into the hydrologic model, example scheme as implemented for the land use in 2012.

3.2. Water quality in the pilot area

According to main focus of PROLINE-CE we used the nitrate concentrations in the shallow groundwater as an indicator to trace the link between land use changes and groundwater quality in the Neufahrn pilot area.

First, nitrate and potassium show a high correlation in the shallow groundwater, which can be, but not has to be, an indicator for the application of nitrogen-based fertilizers, such as potassium nitrate, to increase the productivity in agricultural lands (Figure 5).

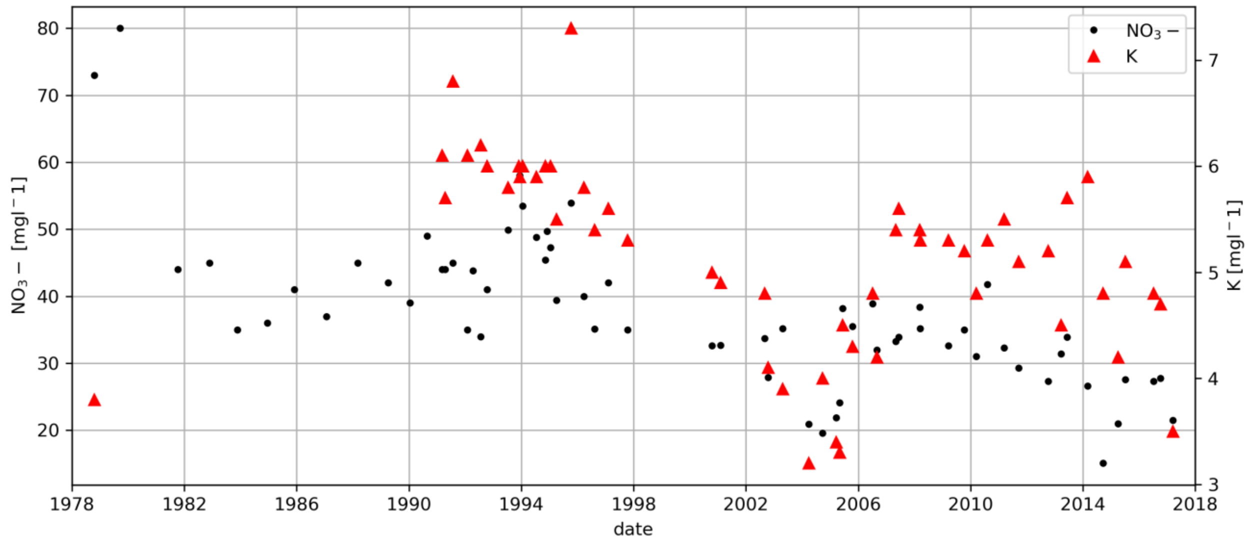

Figure 5: Time series of concentrations of nitrate and potassium as measured in shallow well 1.

Generally, due to excessive use of these fertilizers, plants cannot consume all the nitrogen applied on the field. Therefore, excess nitrate remains in the soil and dissolves into infiltrating water and finally leach into shallow groundwater. The results from 37 years (1981-2017) of groundwater monitoring in the shallow wells show statistically significant negative trends in nitrate concentration. In the period from 1990-2000, the results indicate fluctuations in the nitrate concentrations in all shallow wells (Fig. 6), which we furthermore related to the continuous conversion of grasslands.

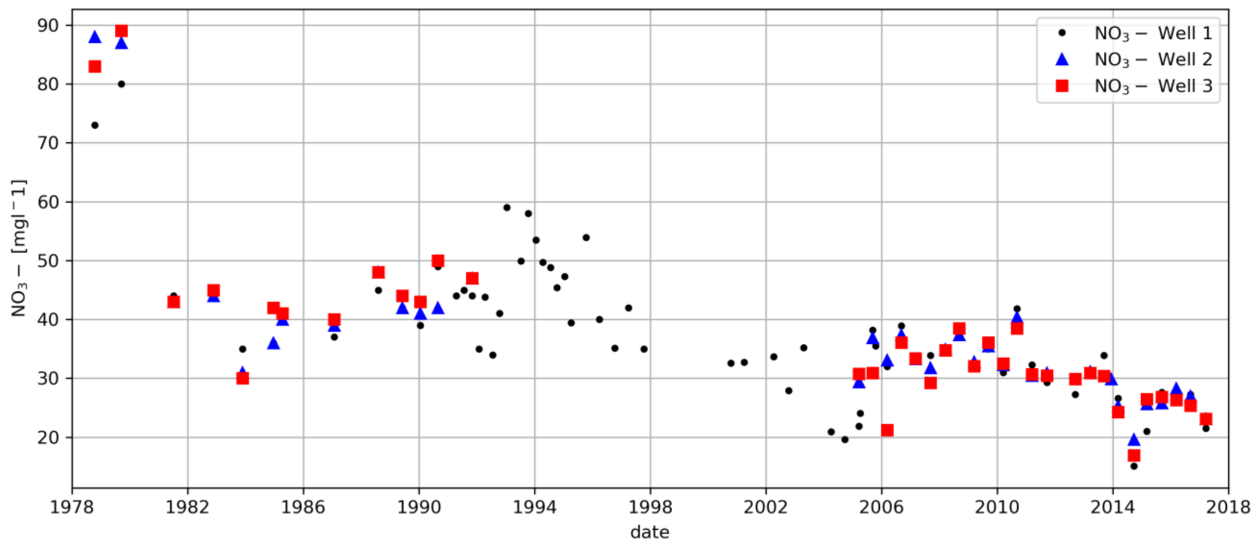

Figure 6: Variation and data gaps of the nitrate concentrations in shallow wells 1 -3.

However, the decreasing trend in the nitrate concentration shows the considerable impact of groundwater and land use management strategies in this area, including decreasing agricultural activities and livestock farms, changing patterns of agricultural products and stricter regulations on fertilizer applications.

The availability of a complete dataset, including water quality and quantity parameters, with a high temporal resolution (e.g. daily or lower) is an important best management practice to properly plan future land use management strategies, based on an in depth understanding of the actual situation and of the history of the site conditions. Moreover, multi parametric portable probes are nowadays widely available for a large set of physical and chemical parameters and the cost per measurement is significantly lower than laboratory analyses.

3.3. Solutions for case specific adaptation of best management practices

Table 2: GAPs and proposed BMPs with recommendations for implementation in Pilot Action.

Actual management practice (GAP)		**Continuous conversion of (permanent) grasslands**	**Public engagement in development of action plans**
Proposed BMP		Continuous monitoring program in both, surface water and groundwater	Finding site-specific solutions by using a hydrologic model with a graphical user interface in a participative approach
Proposed solutions and recommendations	adaptation of existing land use management practices	No adaptation of existing land use management practices required.	No adaptation of existing land use management practices required.
	Adaptation of existing flood/drought management practices	Invest in infrastructure to increase the monitoring network in the pilot action. Installation of gauging stations on the Isar river, identification of piezometers usable to monitor groundwater level, installation of multi parametric probe that measures continuously relevant hydrogeochemical parameters (water level, water temperature, electrical conductivity, pH, Nitrate, dissolved oxygen)	The availability of a hydrological model can provide relevant information for the stakeholders in terms of water quantity and quality and support decision makers in the implementation of existing flood/drought management practices. The use of the proposed BMP has to be intended in a broader framework which can serve as decision support system for managers.
	Adaptation of policy guidelines	The value of monitoring should be more emphasized in the policy guidelines and water suppliers as well as water authorities should receive incentives to better manage available data and to collect more frequently and with a better spatial resolution relevant hydrogeochemical data.	The value of an available hydrological model is not adequately reported in the current guidelines. This tool is of fundamental importance to find efficient site-specific solutions, to test the implementations of solutions proposed by the various relevant stakeholders and to communicate the decision-making process.
Remaining issues to be solved		Not applicable	Not applicable

4. Conclusions

In the presented report, we outlined the BMP’s found for the pilot area Neufahrn bei Freising; we identified a *continuous monitoring program of hydrological data* with a high resolution in time and space as well as *hydrological modelling* as the most suitable BMP’s. In the light of continuous changes in management practices as well as strongly economic-driven land use changes, a monitoring of relevant parameters in surface water and groundwater, such as water level, electrical conductivity, temperature, pH, nitrate among others, sets an appropriate frame to detect impacts of ongoing changes in the hydrological system. Given the enhanced data base, a hydrologic model serves to relate any kind of changes to particular changes in the management system. Moreover, the hydrologic model allows to pre-evaluate the impacts of a planned action and, thus, supports the decision making process from the beginning to the end of an implementation process. Moreover, a comprehensive, understandable and applicable modelling framework can serve as a common tool for all stakeholders, from land owner to decision maker, to jointly elaborate action plans, making decision-making more participatory. An enhanced public engagement further helps to reduce the mistrust between the engaged parties.

5. References

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